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14. ABSTRACT The research focused on improvements in diagnosis and prognosis of crack detection through extensive use of probabilistic techniques. A unique feature of the research is that it identifies the material properties relevant to damage propagation at the same time that it performs diagnosis and prognosis. As such, it has the potential of turning aircraft into <i>flying fatigue laboratories</i> and contributing to substantial improvements in the accuracy of aircraft <i>digital twins</i> . Specific accomplishments are include the development of frequency-wave-number migration technique, image-segmentation technique, use of Bayesian techniques for combining sensors and actuators, and for narrowing down uncertainty in material properties that govern crack propagation. Together, the research is expected to substantially advance research into making structural health monitoring practical for Air Force aging planes.					
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Title: Probability-Based Integration of Structural Health Monitoring into the Aging Aircraft Sustainment Program
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Investigator: Nam-Ho Kim, University of Florida.
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Overall view: The research focused on improvements in diagnosis and prognosis of crack detection through extensive use of probabilistic techniques. A unique feature of the research is that it identifies the material properties relevant to damage propagation at the same time that it performs diagnosis and prognosis. As such, it has the potential of turning aircraft into *flying fatigue laboratories* and contributing to substantial improvements in the accuracy of aircraft *digital twins*. Specific accomplishments are listed below. Item 1 was needed to improve accuracy, item 2 to improve image sharpness, and item 3 to take full advantage of multiple pairs of sensors or actuators. Together they provide more accurate diagnosis. Item 4 is the realization of the flying fatigue laboratory concept, and item 5 provides an efficient method that extracts maximum accuracy in prognosis from the narrowed down material properties. Together, the research is expected to substantially advance research into making structural health monitoring practical for Air Force aging planes.

Specific Accomplishments:

1. Developed a frequency-wave number (f-k) migration technique for an imaging the damage in a plate with the through-the-thickness crack.

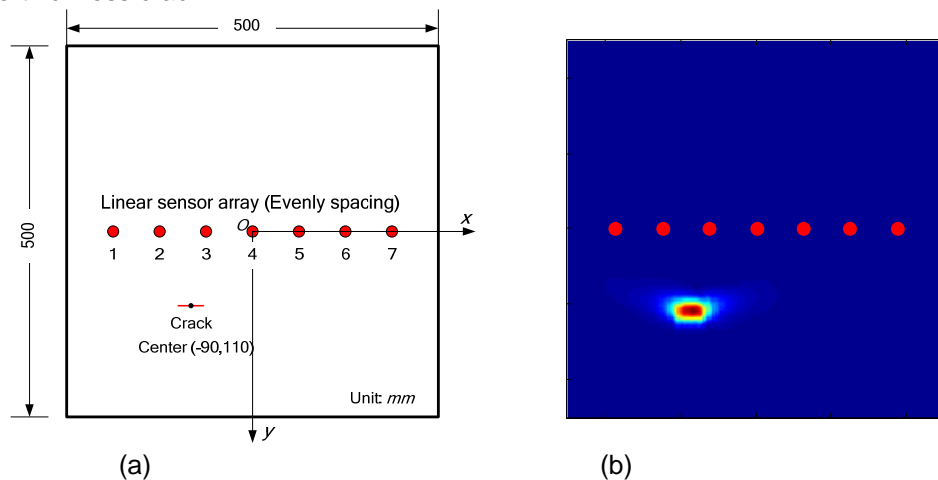


Figure 1(a) Geometry of f-k migration simulation and (b) damage image with a single crack

2. Developed an image segmentation technique for quantifying the damage size using Markov Random Field and Bayesian statistics.

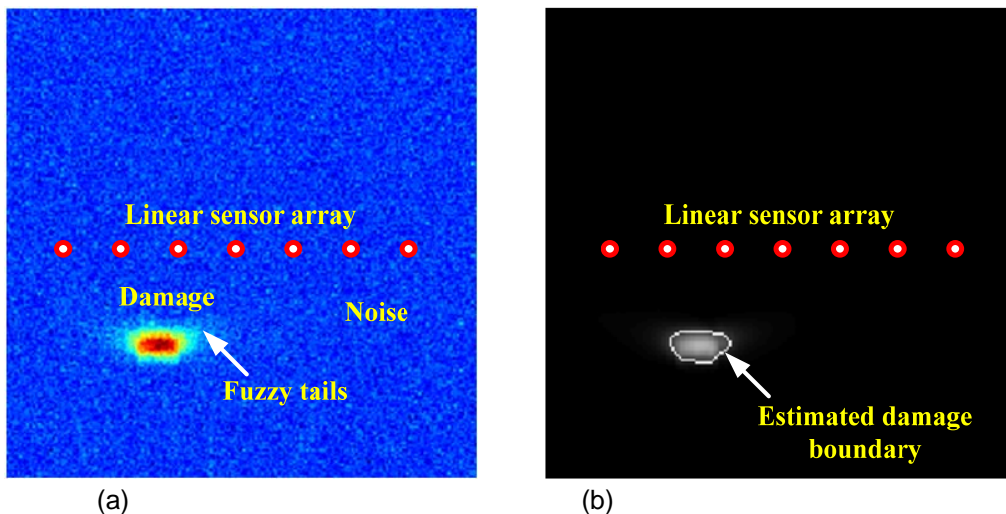


Figure 2 (a) An image by f-k migration and (b) the Bayesian based segmentation

3. Application of Bayesian updating for combining measurements from multiple actuator-sensor pairs for simple damage detection paradigm.

4. Develop Bayesian updating to progressively narrow the uncertainty in damage growth parameters in spite of noise and bias in sensor measurements. Figure 3(a)
5. Developed a probabilistic model for damage size distribution from the damage imaging and estimated the distribution of remaining useful life (RUL) using a combination of Bayesian updating and least squares fitting of damage growth parameters.

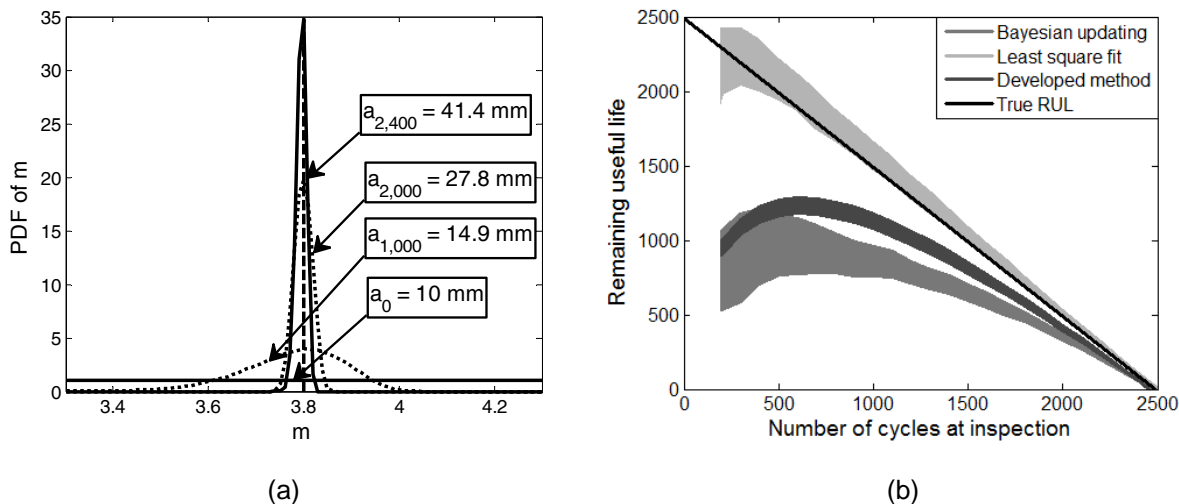


Figure 3 (a) A very wide initial distribution of the exponent in Paris law for crack growth is successively narrowed as crack measurements accumulate (b) By combining Bayesian updating and least squares identification of crack growth, the

Archival publications (published) during reporting period:

1. A. Coppe, R. T. Haftka, N. H. Kim, and P. Ramu, Optimization of distribution parameters for estimating probability of crack detection, 12th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Victoria, British Columbia, Canada, 10-12 September, 2008.
2. A. Coppe, R. T. Haftka, N. H. Kim, C. Bes, A statistical model for estimating probability of crack detection, International Conference on Prognostics and Health Management (PHM), Denver, CO, 6-9 October, 2008.
3. J. An, R. T. Haftka, N. H. Kim, F. G. Yuan, B. M. Kwak, Bayesian approach for structural health monitoring--application to migration technique, US-Korea Workshop on Structural Health Monitoring, 31 May - 3 June, 2008.
4. G. Li, F. G. Yuan, R. T. Haftka, and N. H. Kim, "Image Segmentation of Damage in Integrated Structural Health Monitoring," 2008 Aviation Safety technical Conference, Denver, October, 2008.
5. A. Coppe, R. T. Haftka, N. H. Kim, and F. G. Yuan, "Reducing Uncertainty in Damage Growth Properties by Structural Health Monitoring," Annual Conference of the Prognostics and Health Management Society, 2009, CO., Denver, September, 2009.
6. A. Coppe, R. T. Haftka, N. H. Kim, and F. G. Yuan, Statistical Characterization of Damage Propagation Properties in Structural Health Monitoring, 11th AIAA Non-Deterministic Approaches Conference, Palm Spring, CA, 4-7 May, 2009.
7. J. An, R. T. Haftka, N. H. Kim, and F. G. Yuan, B. M. Kwak, "Compensation for Decay of Signal Strength in Damage Detection by Ultrasonic Imaging: Application to Migration Technique," SDM Conference, 2009.
8. G. Li, F. G. Yuan, R. Haftka, and N. H. Kim, "Bayesian Segmentation for Damage Image using MRF Prior," *Proceedings of SPIE*, San Diego, April, 2009.
9. G. Li, F. G. Yuan, R. Haftka, and N. H. Kim, "Bayesian based Image Segmentation for Damage Quantification," In preparation, 2010.
10. G. Li, F. G. Yuan, R. Haftka, and N. H. Kim, "Probabilistic Damage Qualification and Structural Prognosis," In preparation, 2010.

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Mr. Jungeun An (PhD expected December 2010)
 Ms. Alexandra Coppe (PhD expected May 2011)
 Mr. Gang Li (PhD expected in August, 2009)
 Mr. Q. Wu (PhD expected in August, 2013)

